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rupting its fringing reefs; this is taken to mean that earlier fringing reefs were drowned by rapid submergence, so that they did not grow up in off-shore barrier reefs.

The Great Barrier reef of Australia, the largest reef in the world, with a length of some 1200 miles and a lagoon from 15 to 70 or more miles wide, has grown upward during the recent subsidence by which the Queensland coast has been elaborately embayed, as was pointed out by Andrews in 1902.

Five islands of the Society group exhibit unequivocal signs of recent submergence in their intricately embayed shore lines, as has lately been shown by Marshall; the cliff-rimmed island of Tahiti, the largest and youngest of the group, has suffered moderate submergence after its cliffs were cut, but its bays are now nearly all filled with delta plains; hence a pause or still-stand has followed its latest submergence. All the barrier reefs of this group appear to have been formed during the recent submergence, due to regional subsidence, that embayed their central islands.

A METHOD OF PROPHESYING THE LIFE DURATION OF SEEDS

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Seeds that will withstand drying in the air without injury retain their viability under herbarium conditions from one to one hundred and fifty years. Seeds that will not withstand drying in the air generally have a longevity of only a few months. Ewart[1] has suggested that seeds retaining their viability for three years or less be called microbiotic; for three to fifteen years, mesobiotic; and for more than fifteen years, macrobiotic. The cause of the loss of viability with storage has been a subject of considerable study. Two explanations have been offered: exhaustion of stored foods and degeneration of digestive and oxidizing enzymes. Both of these explanations have proved incorrect for both foods and enzymes are present in almost full force for some years after viability is lost. Certain facts have led us to surmise that the gradual loss of viability with storage is due to a slow coagulation of the proteins in the plasma of the embryo. The fall of longevity with rise of temperature and of moisture content of the seed indicate this.

Certain known facts concerning proteins make the experimental investigation of this hypothesis possible. Chick and Martin[2] have shown that the coagulation temperature of proteins is not a fixed point as is the melting point of metals and other substances. Coagulation is a function of duration of heating, percentage of water present, and the reaction of the protein as well as of the temperature. The lower the water content the more heating is required for coagulation. Acidity favors and alkalinity retards coagulation by heat. Buglia[3] established the following time-temperature formula for the coagulation of proteins: $T = a - b \log Z$, in which T = temperature in degrees Centigrade, Z = time in minutes, and a and b are constants.

If our surmise is correct that the loss of viability of seeds with storage is a matter of coagulation of cell proteins of the embryo, this time-temperature formula for the coagulation of proteins should be applicable as a temperature-life duration formula for seeds. In experiment, of course, the life duration determined must be at relatively high temperatures in order to make the time within the range of an experiment. This calls for temperatures ranging from 50–100°C. for air dry seeds. So far we have used the method of reflux of ethyl or methyl alcohol or mixtures of these with water as a means of obtaining constant temperatures. This gives a range of temperature from about 65–99°C. and a variation at any temperature of less than ± 0.1°C. Delayed germination and lack of resistance of heated seeds to fungal attack made sterilization imperative. Silver nitrate to an aqueous solution of which the coats of various seeds are impervious proved an effective sterilizing agent.

TABLE I

Record Sheet No. 21. Turkish Red Wheat

April 10, 1914. Temperature 87.5°C. Moisture 12%. Percent germinated in heavy figures. Percent partially germinated in light figures

Time, days for germination	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Control	0	2	2	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0
	92	92	92	93	95	95	98	98	98	98	98	98	98	98	98	98	98	98
Heated for 7 minutes			0	15	12	7	8	7	8	7	5	3	3	4	4	4	3	2
			2	5	27	41	49	55	61	64	67	70	72	72	72	72	73	74
“ “ 8 “					4	8	8	7	8	7	5	3	1	5	1	1	1	0
					5	10	25	30	35	41	47	52	54	54	58	59	59	60
“ “ 9 “						2	4	4	5	4	5	4	5	2	3	6	5	4
						2	4	8	10	11	18	25	28	32	34	35	37	38
“ “ 10 “										1	3	4	6	4	3	3	4	5
										0	0	0	0	4	5	9	11	11
“ “ 11 “												1	1	0	0	1	2	1
												1	1	2	4	4	4	5
“ “ 12 “													2	2	2	2	2	2
													0	0	0	2	2	2
“ “ 13 “																		
																0	0	0

Table I shows the data gained from a single experiment. Three things stand out prominently as results of heating: delay in germination, fall in germination percentage, and appearance of abnormal germination. The abnormal germination (root without stem or stem without root) are shown in light type. All these characters appear in seeds stored for a long time at room temperatures, indicating the likeness of the change whether it takes place at a high temperature in a short time or at a low temperature acting for a long time. In Table II are shown the life durations at various temperatures as found by experiment and the calculated temperatures for the various life durations. We have supplied for another variety of wheat one record of longevity by White[4] in which the time was definitely known as eight years and the moisture estimated at 12 percent and the temperature at 20°C. In all these failure of 75 percent to germinate after nineteen days is chosen as the end point. The calculated temperatures of the table were found by solving for the constants a and b by the method of least squares from the found values of T and Z, and from these calculating T for the various values of Z.

TABLE II

Germination Record Turkish Red Wheat

Theoretical temperature calculated by formula $T = a - b \log Z$

T = Temp Celsius, Z = Time of Heating, $a = 98.88$ $b = 11.78$

Trial No.	A	B-C	D-E-D	G	H	I	J	K-L	N	N	O	P
Duration minutes	7	8	9	10	15	18	45	50	50	120	315	8 yrs.
Found temp.	89.2	87.7	87.5	87.5	84.4	84.4	78.9	79.1	78.5	75.8	71.3	20±
Calc. temp.	88.9	88.2	87.6	87.1	85.0	84.1	79.4	78.9	78.9	74.4	69.5	20.9

The rather close agreement between calculated and found values indicate that the time-temperature formula for the coagulation of proteins can be applied as a temperature-life duration formula for seeds, at least under the condition of these experiments. Much more work is needed to establish the general application of this principle. Several more life durations should be determined for wheat as a mesobiotic seed. The life duration with 12 percent moisture should be run at several temperatures ranging from 50–70°C. A large number of determinations should also be made with some moisture content between 16–20%. Such seeds will show much shorter life durations. Determinations should also be run for 2–3% moisture which will give greater life durations. Similar determinations should be made for a macrobiotic seed, such as sweet clover for which we have reliable records of longevity, as well as a microbiotic form. There are several matters that may limit the application of this formula:

1. Increase of the acidity of the seed will hasten coagulation of the cell proteins. Such a change is known to occur in seeds of certain Rosaceae, at least if stored in the imbibed condition.

2. Lepeschkin[5] found that in active plant cells a redispersal of cell proteins is going on coincidently with coagulation. As a consequence at high temperatures where the coagulation was rapid the found and calculated life durations agreed closely; while at lower temperatures where redispersal is prominent the calculated life durations were much shorter than the found values. In the low water content of air dry seeds it is possible that the redispersal of proteins is of little significance. This may limit the method to seeds of relatively low water content.

3. A slight error in a and b will give a relatively large error for a life duration at low temperatures such as 0° C. At higher temperatures the error becomes less. In the data above calculated temperature for a life duration of eight years varies little whether a and b are calculated by including White's data at 20° C. or merely from the determinations above 70° C.

4. The lower the water content of seeds the more heating they will withstand and the greater the longevity at moderate and low temperatures. This law has its limits, for excessive drying is itself injurious. In seeds that will endure dessication injury sets in with a reduction of the water much below two per cent, while in forms like *Drosera* it appears before air-dry condition is reached. Our method is, of course limited to degrees of dessication less marked than those producing injury.

5. Undoubtedly longevity under like conditions will vary with different varieties of the same species and even with different crops of the same variety; but the general conditions found for a given crop will probably apply to other crops of the same variety and to other varieties of that species. How far the five points mentioned above will limit the application of this method can only be determined by such experiments as those outlined above.

The work shows possibilities of throwing light on the nature of the process of loss of viability in seeds and of leading to a quantitative statement of the significance of various storage conditions (especially moisture content and temperature) upon the longevity of seeds.

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[1] Ewart, *Proc. Roy. Soc. Victoria*, **2**, 1–210 (1908).

[2] Chick and Martin, *Amer. J. Physiol.*, **40**, 404 (1910); **43**, 1 (1911).

[3] Buglia, *Ztschr. Chem. Indust. Kolloide*, **5**, 291 (1909).

[4] White, *Proc. Roy. Soc. London*, **81** B, 417 (1909).

[5] Lepeschkin, *Ber. Dtsch. Bot. Gesells.*, **30**, 703–714 (1913).